Supersonic Particle Deposition (SPD)

Applications and R&D at ARL

Victor Champagne
US Army Research Laboratory
Weapons & Materials Research Directorate

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Report Documentation Page

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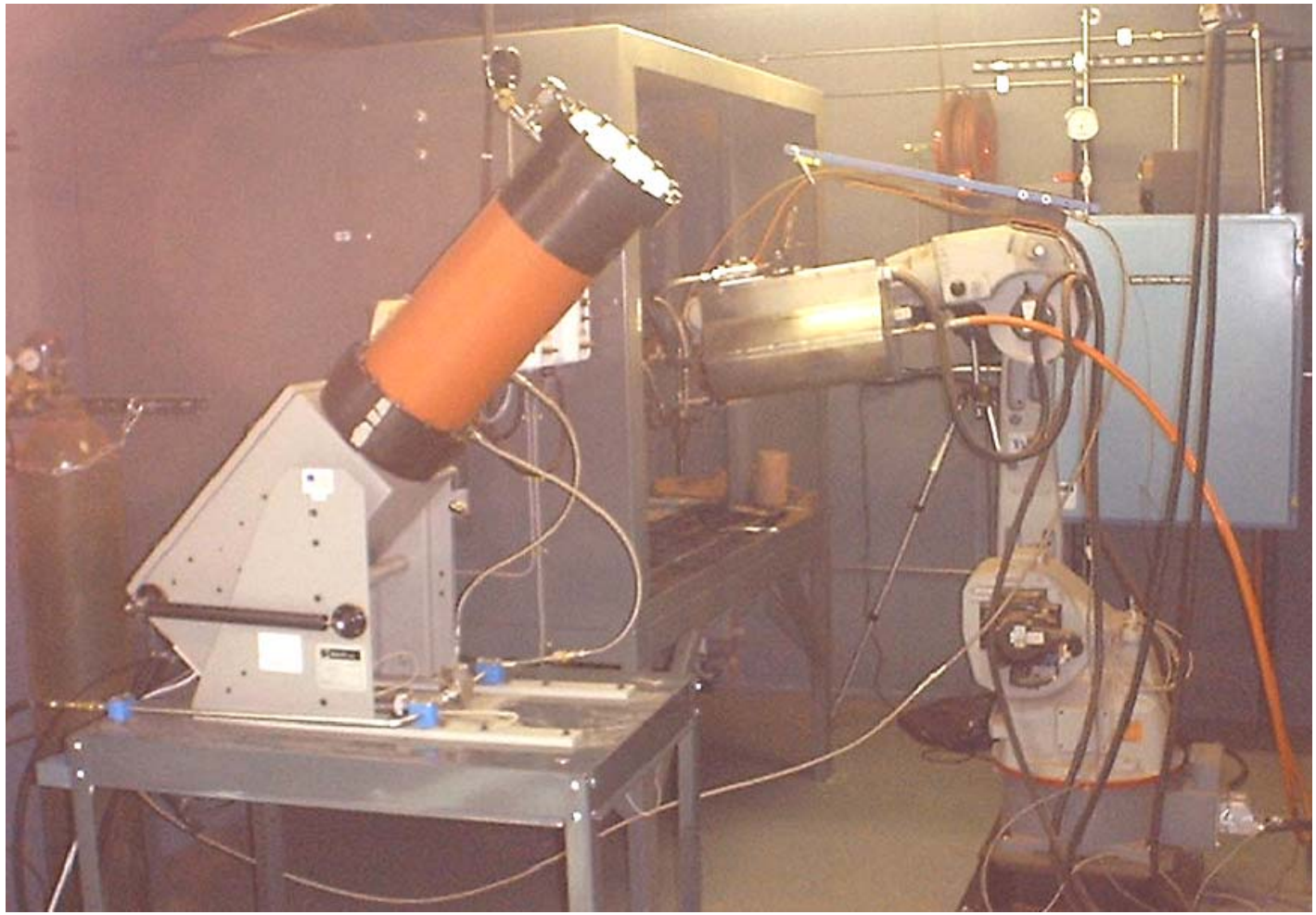
SPD Applications At ARL

1.	EMI Coatings for HMMWV Shelter	General Dynamics
2.	Aluminum Coatings for Mg Housings	Sikorsky Aircraft
3.	Advanced Med. Cal. Munitions	ARL R&D
4.	Fuel Cells	ARL R&D
5.	Heat Exchangers	ARL R&D, U of Maryland
6.	Armor Tile Encapsulation	ARL R&D, PennState
7.	W-Cu Coatings (Classified)	ARL-R&D

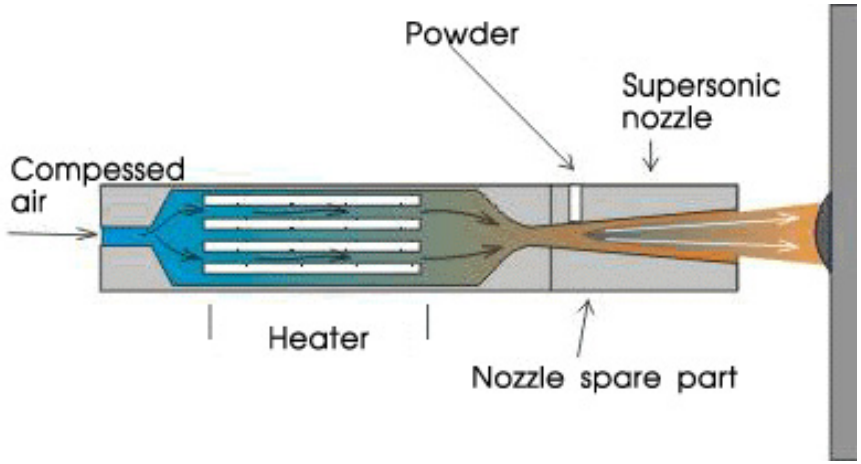
ARL SPD Research Team

Victor Champagne	Materials Engineer	(410) 306-0822
Dr. Christopher Norfolk	Materials Engineer	(410) 306-0818
Dr. Dennis Helfritch	Scientist	(410) 306-1928
Phillip Leyman	Process Engineer	(410) 306-0818
Robert Lempicki	Process Engineer	(410) 306-0808
Dr. William DeRosset	Modeling/Simulation	(410) 306-0816

Army Research Laboratory
SPD System



Portable SPD

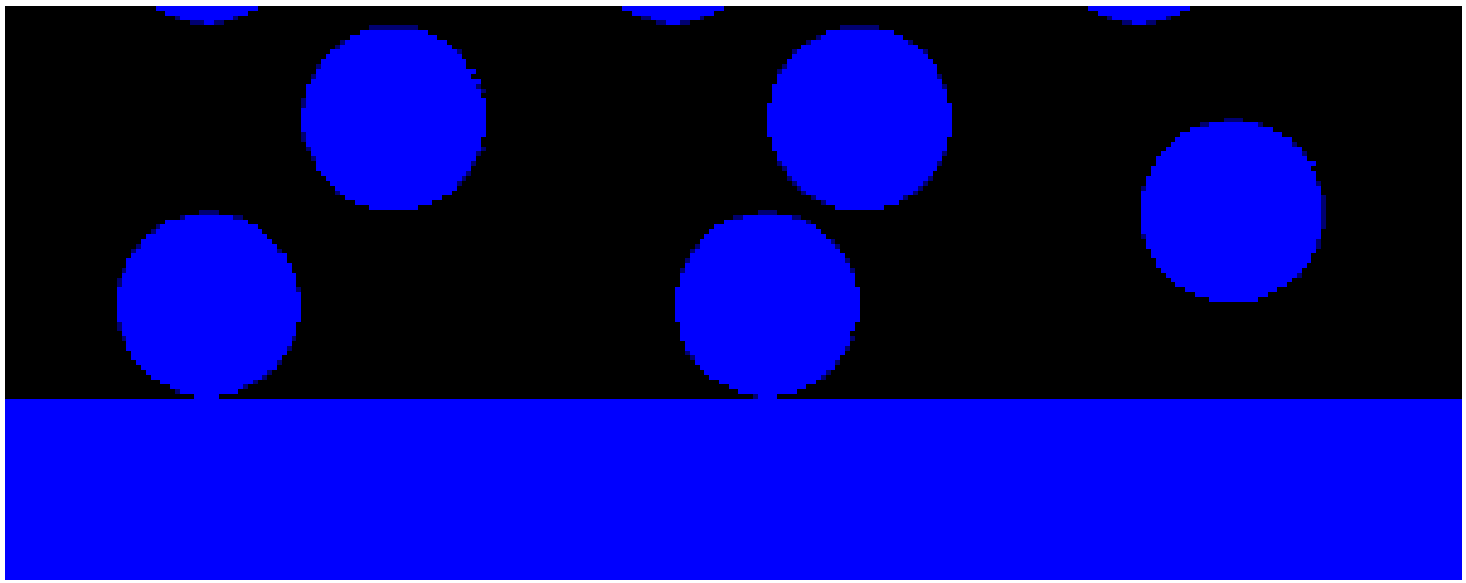


- Downstream Powder Feed
- Portability/Field Repair
- Slightly Lower Particle Velocity
- Special Powder Formulation
- ARL Has Two Portable Systems

SPD Advantages

- **Low temperature**
  - Solid State Process
  - Low residual stresses
  - Minimal grain growth
- **Little oxidation**
  - good electrical/thermal conductivity
  - electrical conductivity: 80% of OFHC Copper
- **High deposition rates and efficiencies**
  - rates - up to 20 kg/hr.
  - efficiencies generally 50 - 80%
- **Wide variety of coating materials and substrates**
  - Al, Zn, Sn, Cu, Ni, Ti, Ta, Co, Fe, Nb, Mo, W.

Particle/Substrate Interaction*



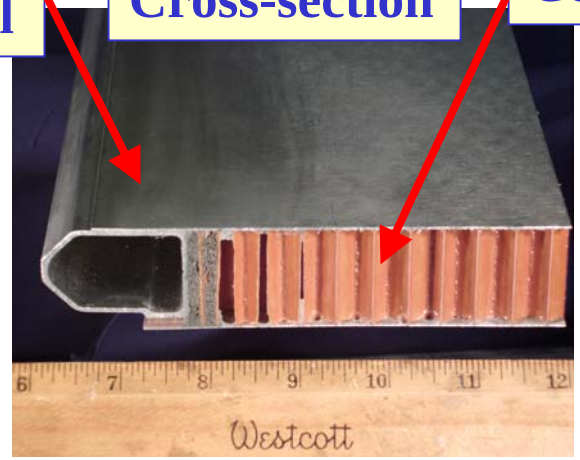
*from H. Assadi, www.modares.ac.ir/eng/ha10003/CGS.htm

EMI Shielding for HMMWV Shelter and Al Coating for Helicopter Mg Housings-FY05 Effort

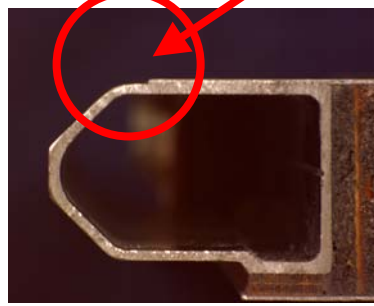
6061-T6 Al

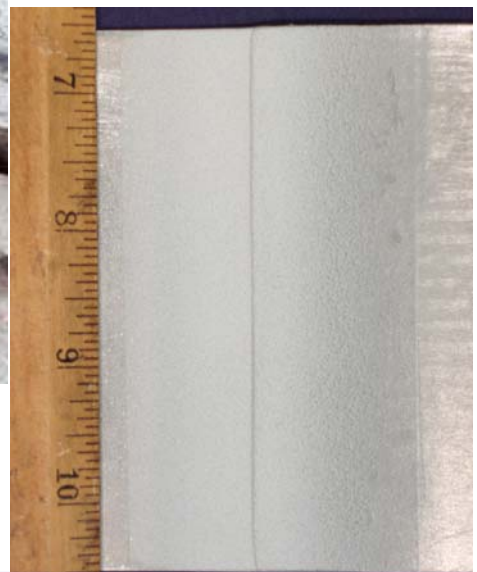
Cross-section

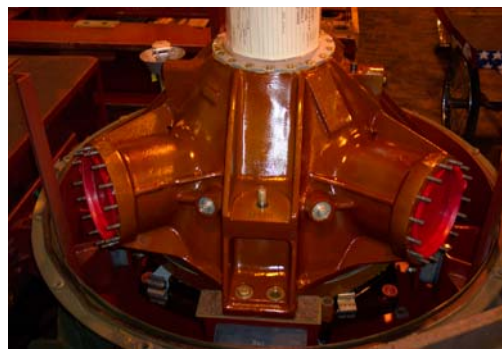
Composite



Lap joint







Supersonic Particle Deposition

AL EMI Coating on lap joint seam

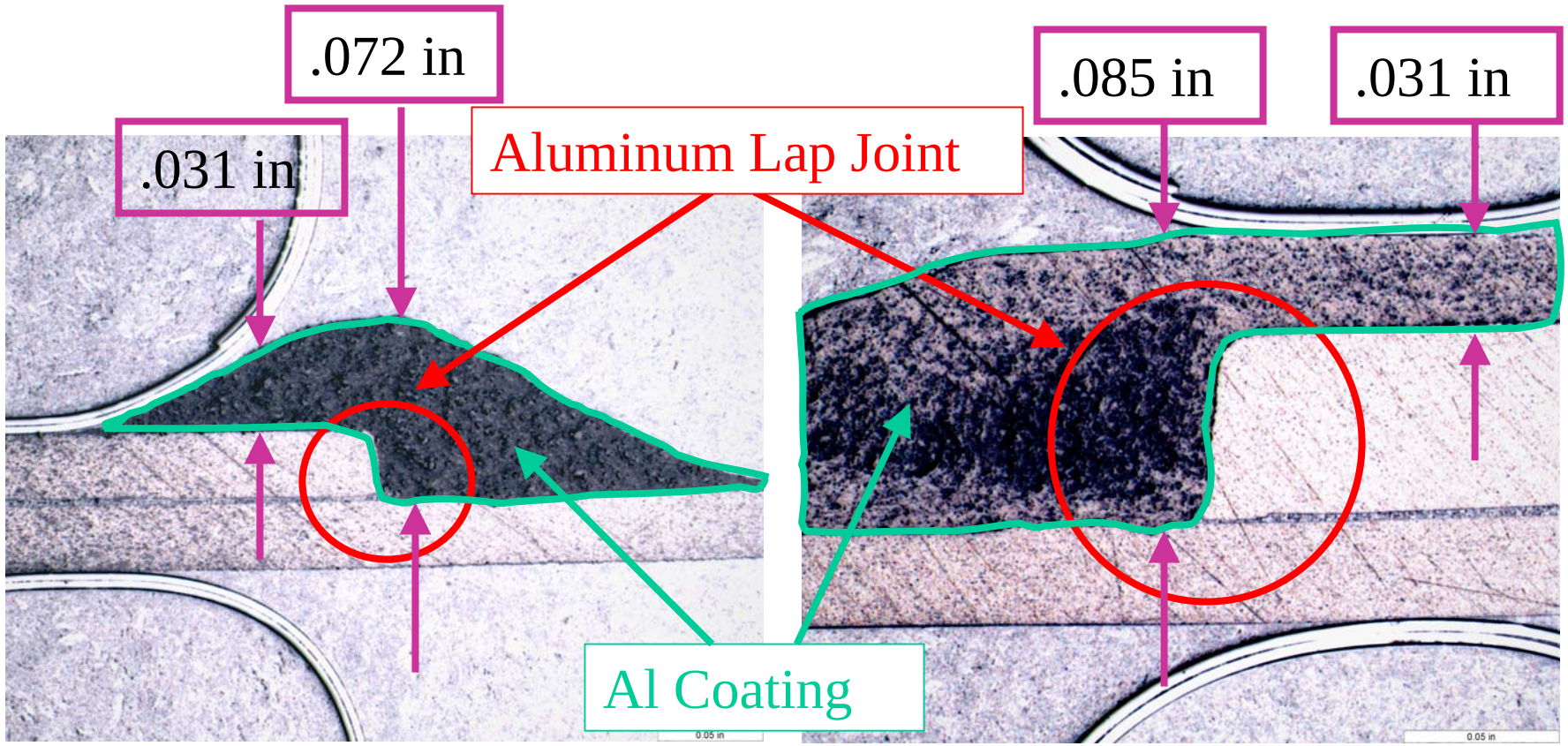
The main rotor transmission gearbox in the UH60 Blackhawk.

HMMWV-mounted Lightweight Shelter

Metallographic Cross-Sections of EMI Coatings

Supersonic Particle Deposition

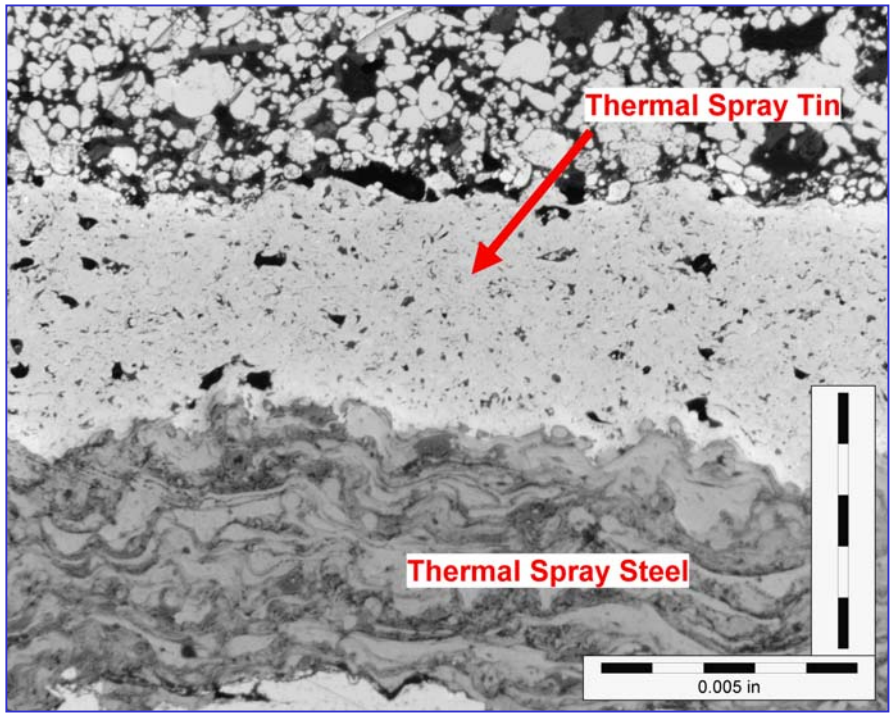
High Velocity Oxy Fuel

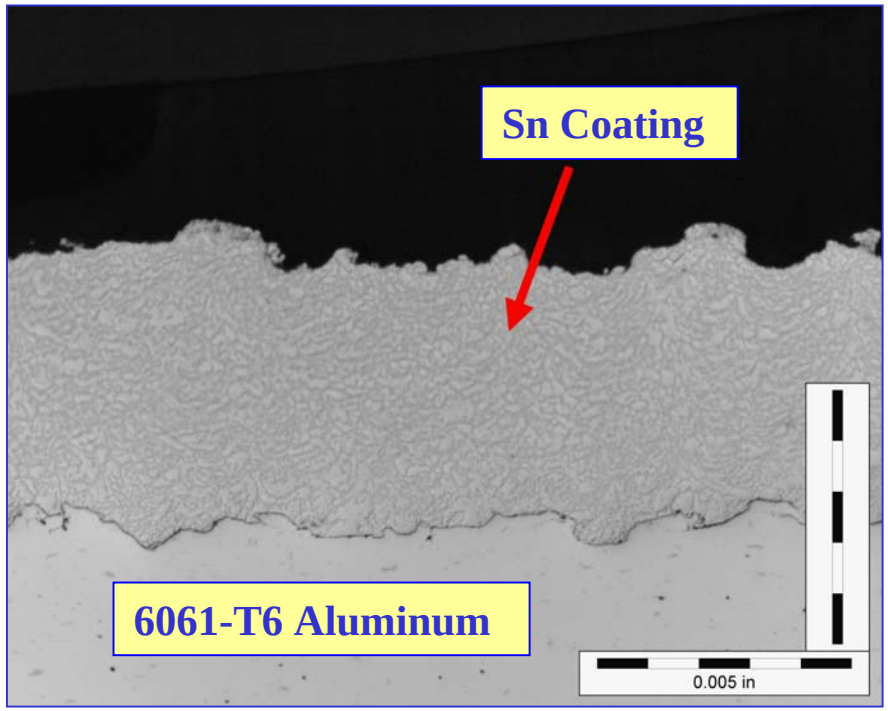


Hand-held portable SPD System

Automated HVOF System

Flame Spray vs. Supersonic Particle Deposition





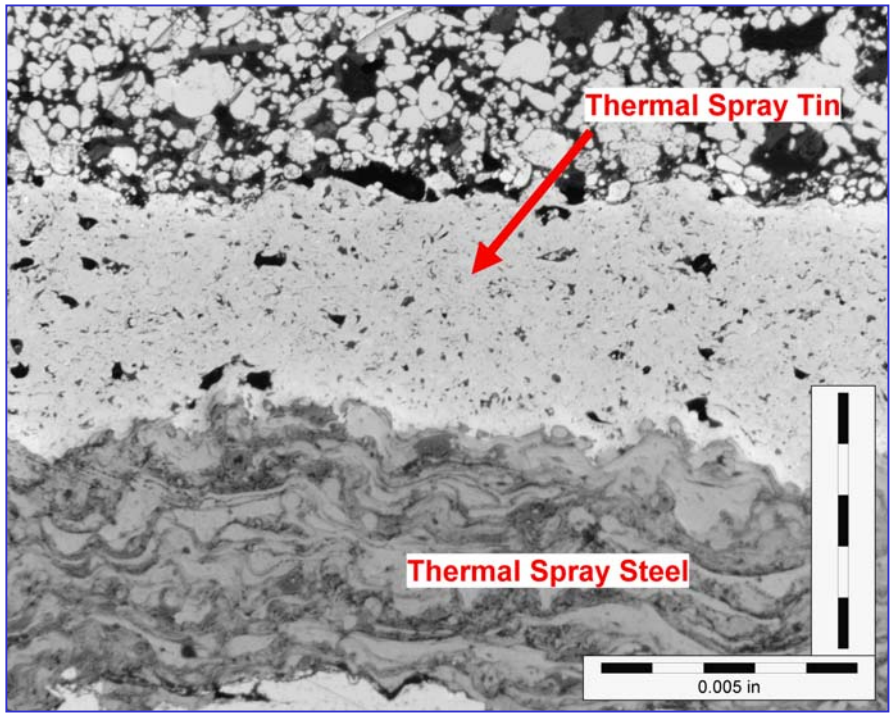
Flame Spray Sn and Steel Coating

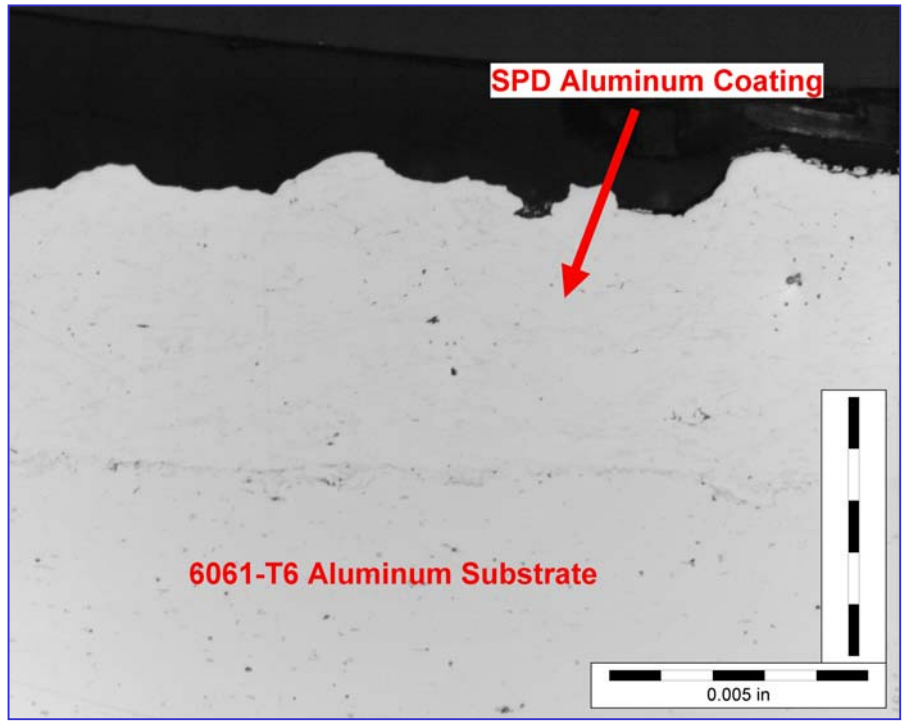
SPD Sprayed Sn Coating

~12.2% Porosity

~.18% Porosity

Flame Spray vs. Supersonic Particle Deposition





Flame Spray Sn and Steel Coating

SPD Sprayed Al Coating

~12.2% Porosity

~.83% Porosity

Portable SPD Application

Cost of SPD

Cost to operate Portable SPD System

Utilizes regular air at no cost.

Aluminum powder cost is $9.70/lb.

One quarter pound of powder was used to coat the test piece

It took 1.5 min. to spray a 1ft section which equates to **~$2.43/ft.** This only includes gasses and powder. It does not include cost to run the equipment (operator, gun parts and overhead).

$2.43/ft. for .031 in coating or $.60/ft. for .008 in coating

Cost of HVOF Coating

Cost to operate Metco Diamond Jet HVOF System

Hydrogen - $8.17 per bottle $50/hr. Oxygen - $5.25 per bottle $15/hr.

Aluminum powder cost is $13.27/lb. @30grams/min. $53/hr.

Traverse rate 600 mm/sec or 23.6 inches/sec.

40 passes is what was used to spray the test piece.

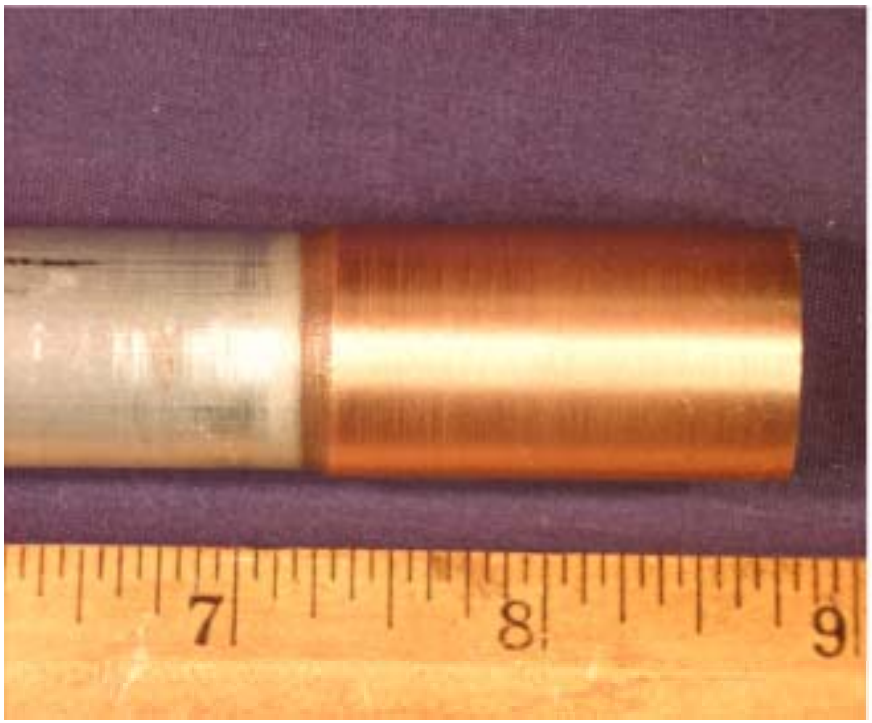
It took 1 min. to spray a 2ft section which equates to $2.05 or ~**$1.00/ft.** This only includes gasses and powder. It does not include cost to run the equipment (operator, gun parts and overhead).

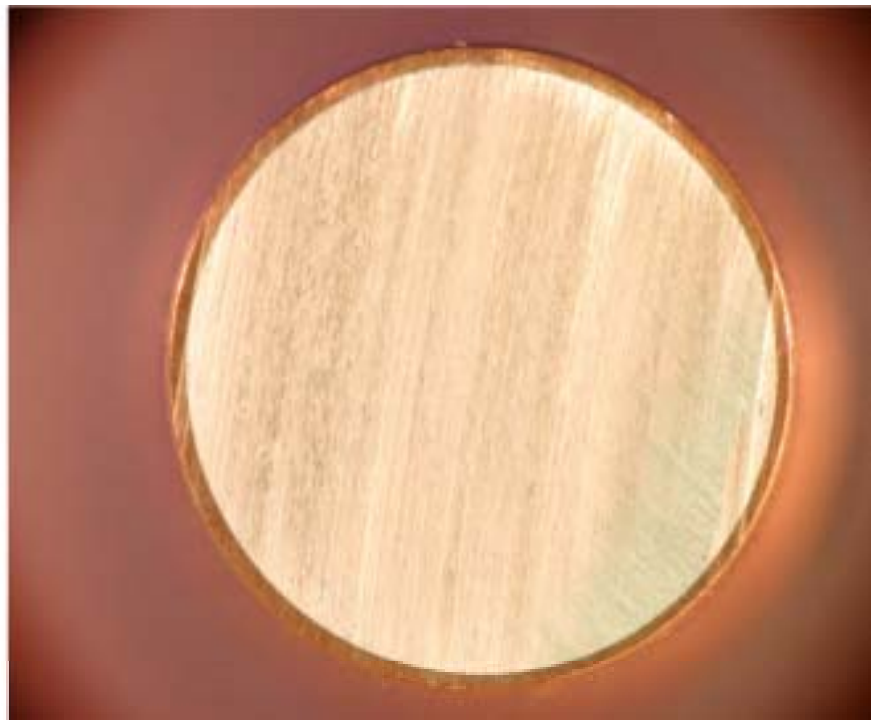
$1.00/ft. for .031 in coating or $.25/ft. for .008 in coating

Conclusions SPD for HMMWV

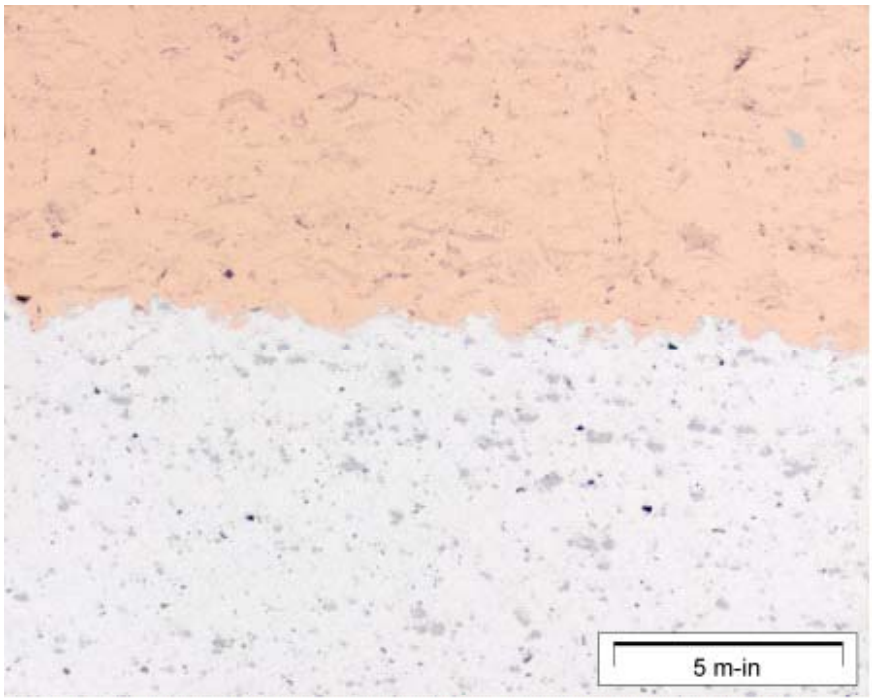
- SPD can provide EMI Coatings for the HMMWV superior to Thermal Spray in terms of porosity and conductivity (fewer oxides).
- SPD can easily deposit onto lap joints.
- TAS could be used in conjunction with SPD for butt joints.
- SPD recommended for field repair and for production.

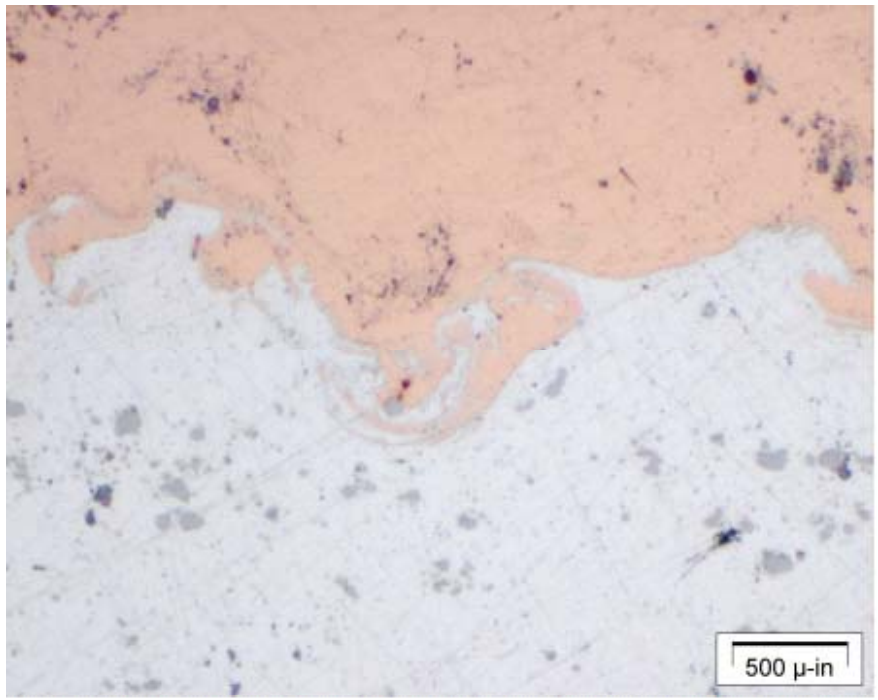
Copper Deposited On Aluminum Rod
Advanced Medium Caliber Munitions





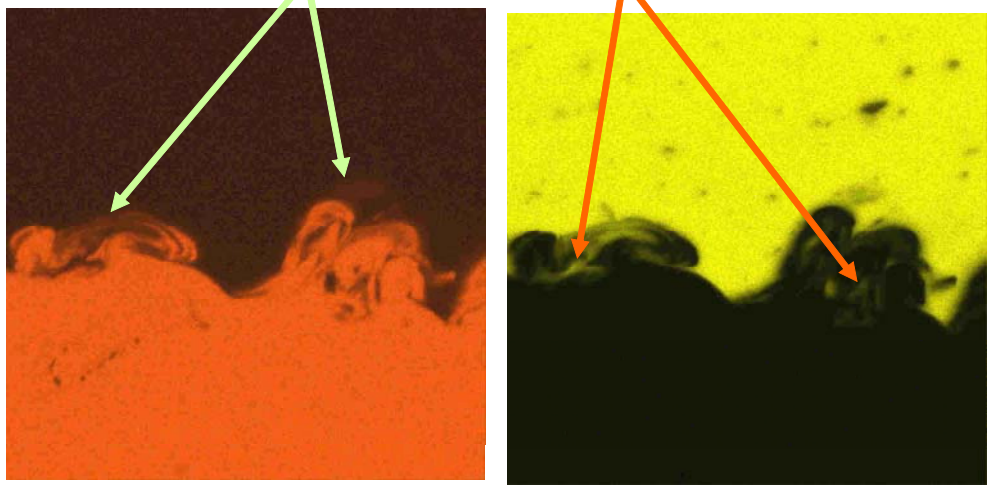
Magnified Interface
Super Plastic Agglomerated Mixing (SPAM)



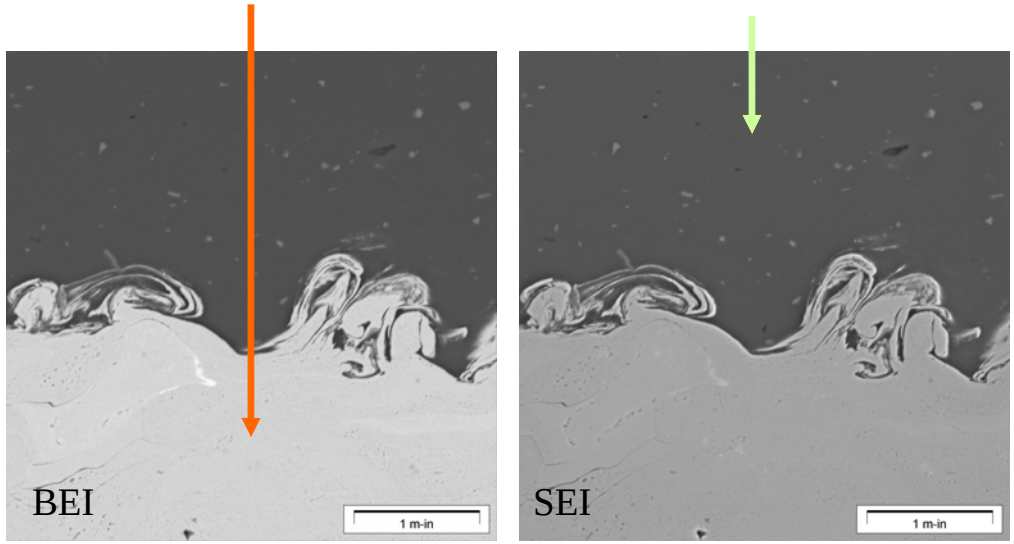


EDS X-ray Mapping of SPAM

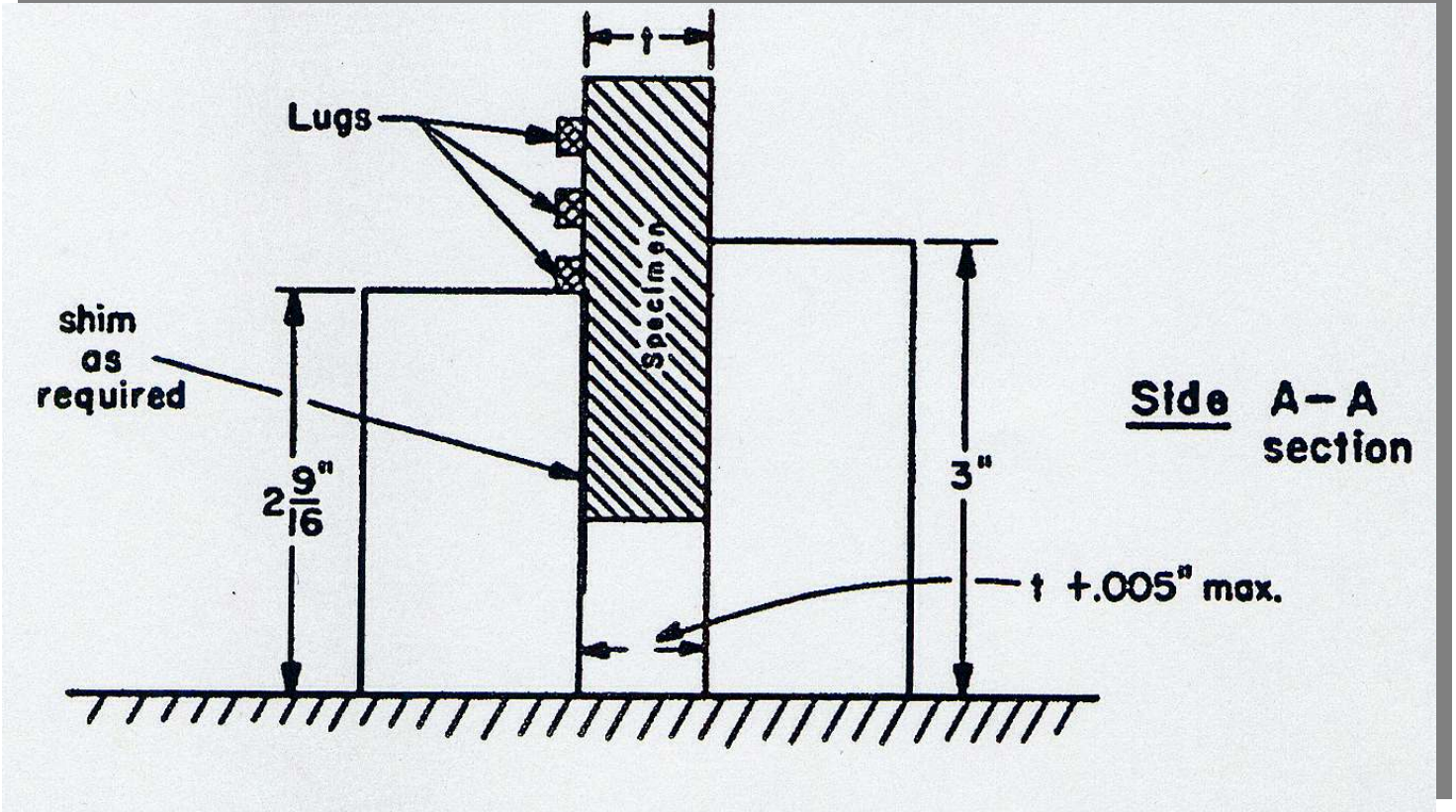
Forced mixing of copper and aluminum.



Copper SPD Coating | **Aluminum Substrate**



Triple Lug Shear Test Fixture



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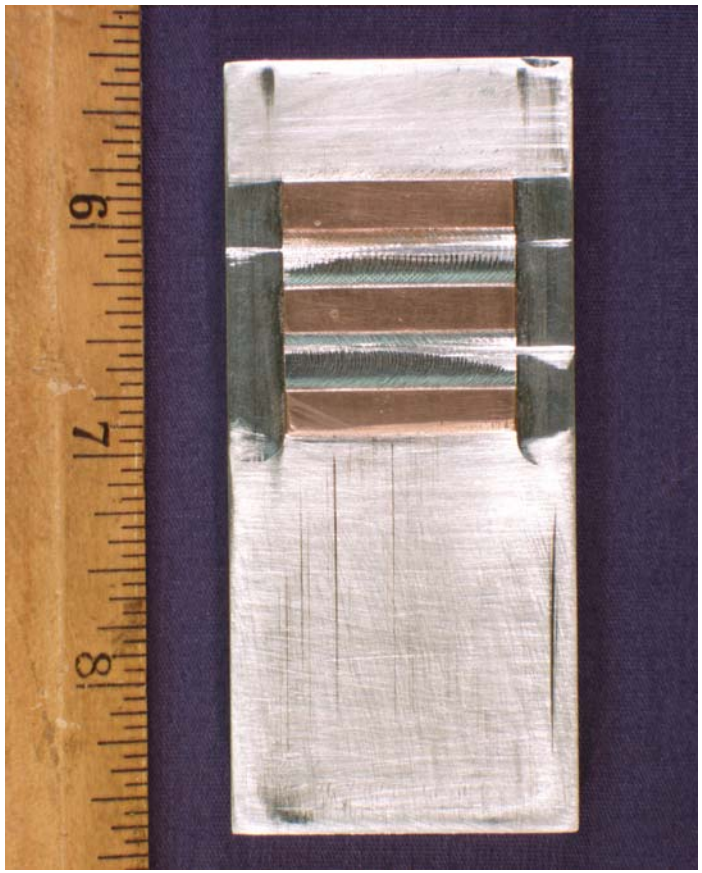
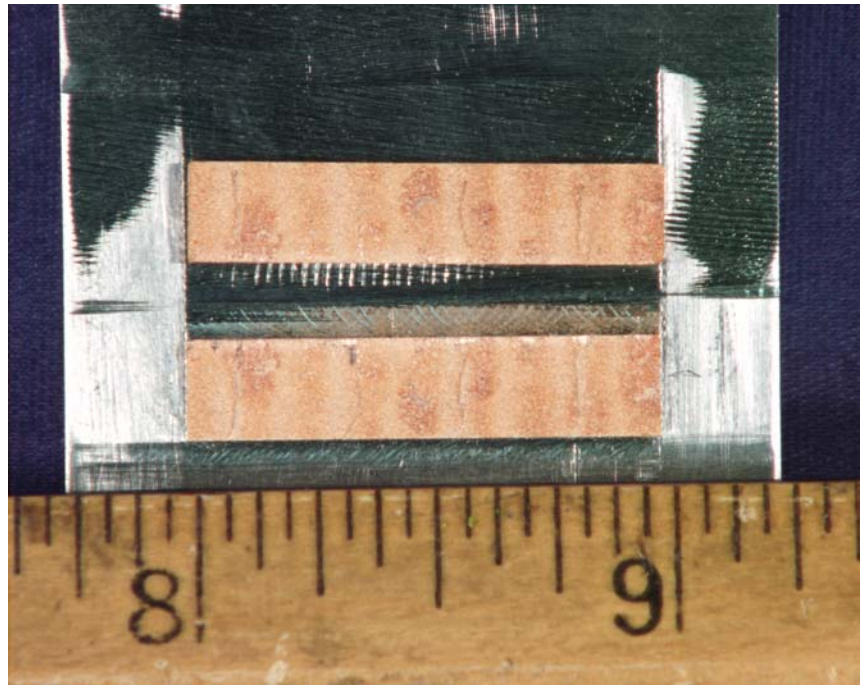
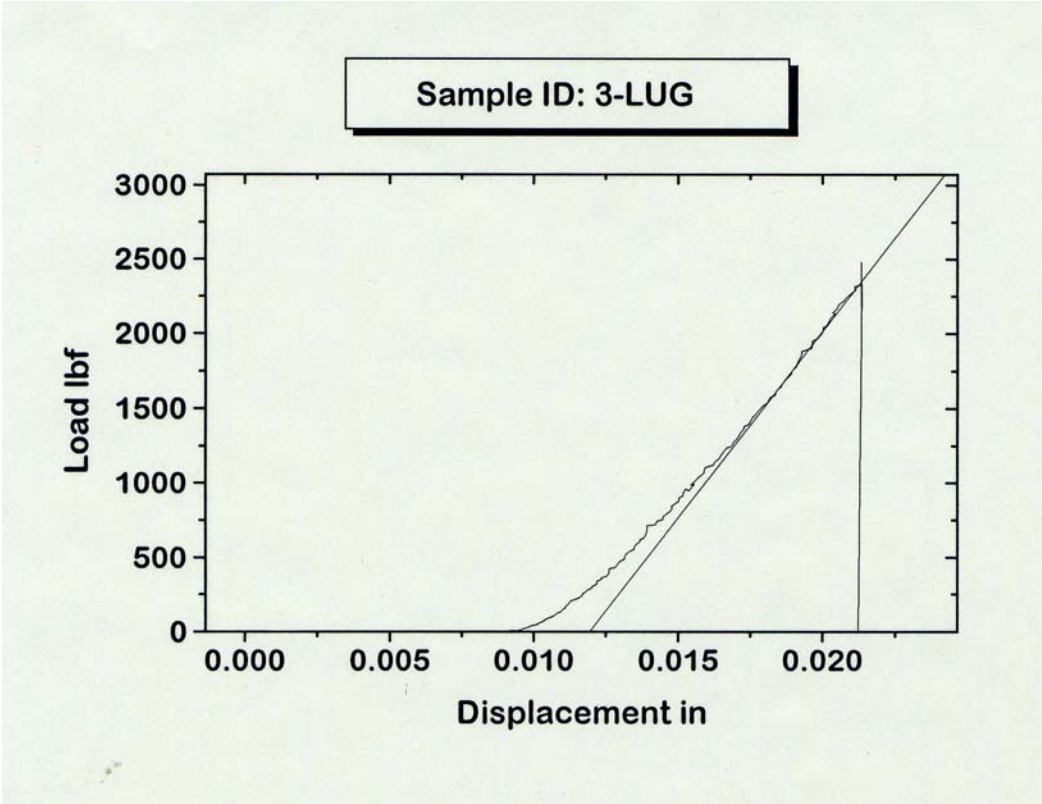
Triple Lug Shear Test Sample





Copper on Aluminum



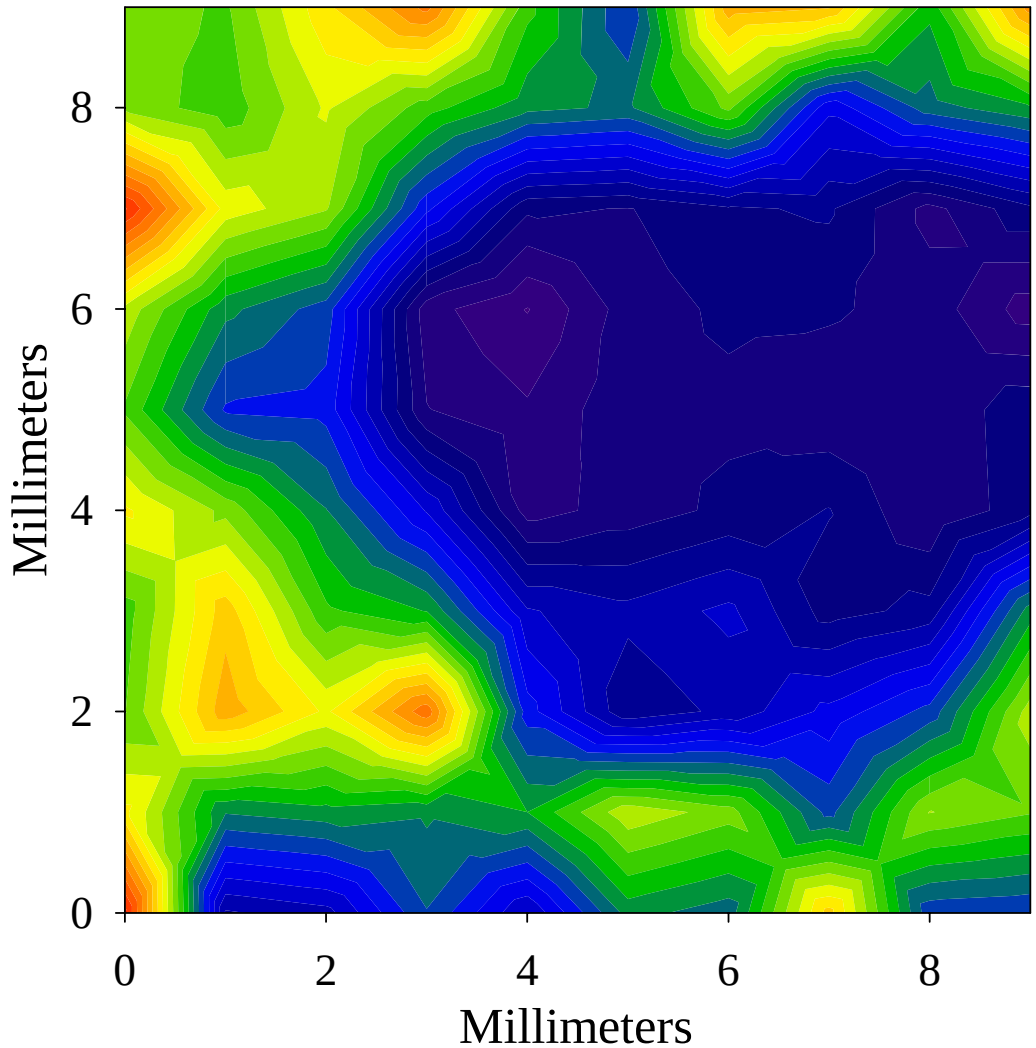
Shear Test Bond Strength = 11,650 psi

Shear Test Results
(Triple Lug Shear Test)

Trial	Pressure psi	Temperature degree C	Stand-off mm	Speed mm/sec	Feed rate gm/min	Shear strength psi
1	280	450	35	50	7	5347
2	280	350	15	50	28	6072
3	380	450	35	10	28	6683
4	380	350	15	10	7	10057

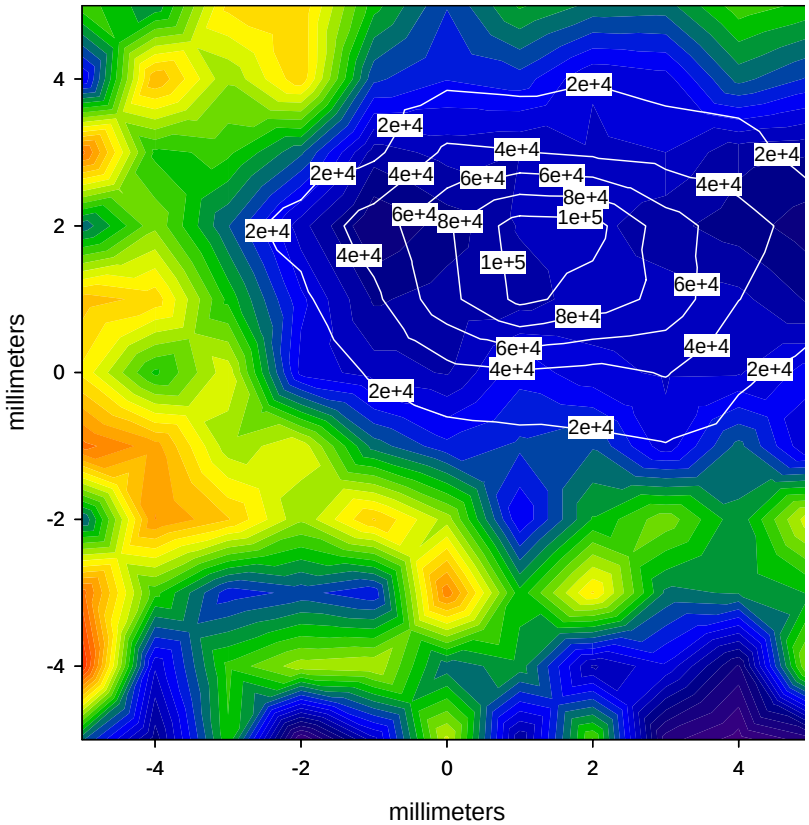
Failure Mode = Cohesive

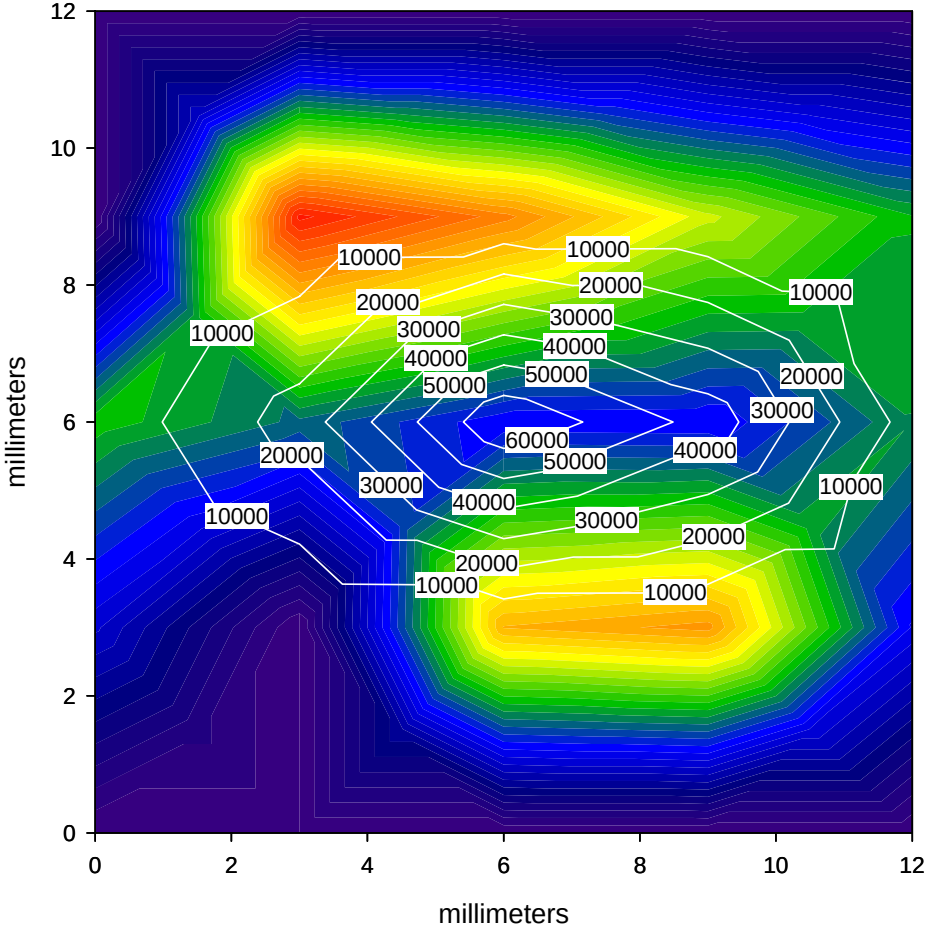
Particle Velocity Distribution



20 micron copper particles
25 mm downstream
400 psi, 400 C N_2 gas

SPD and DYMET
Velocity and Particle Flux Profiles





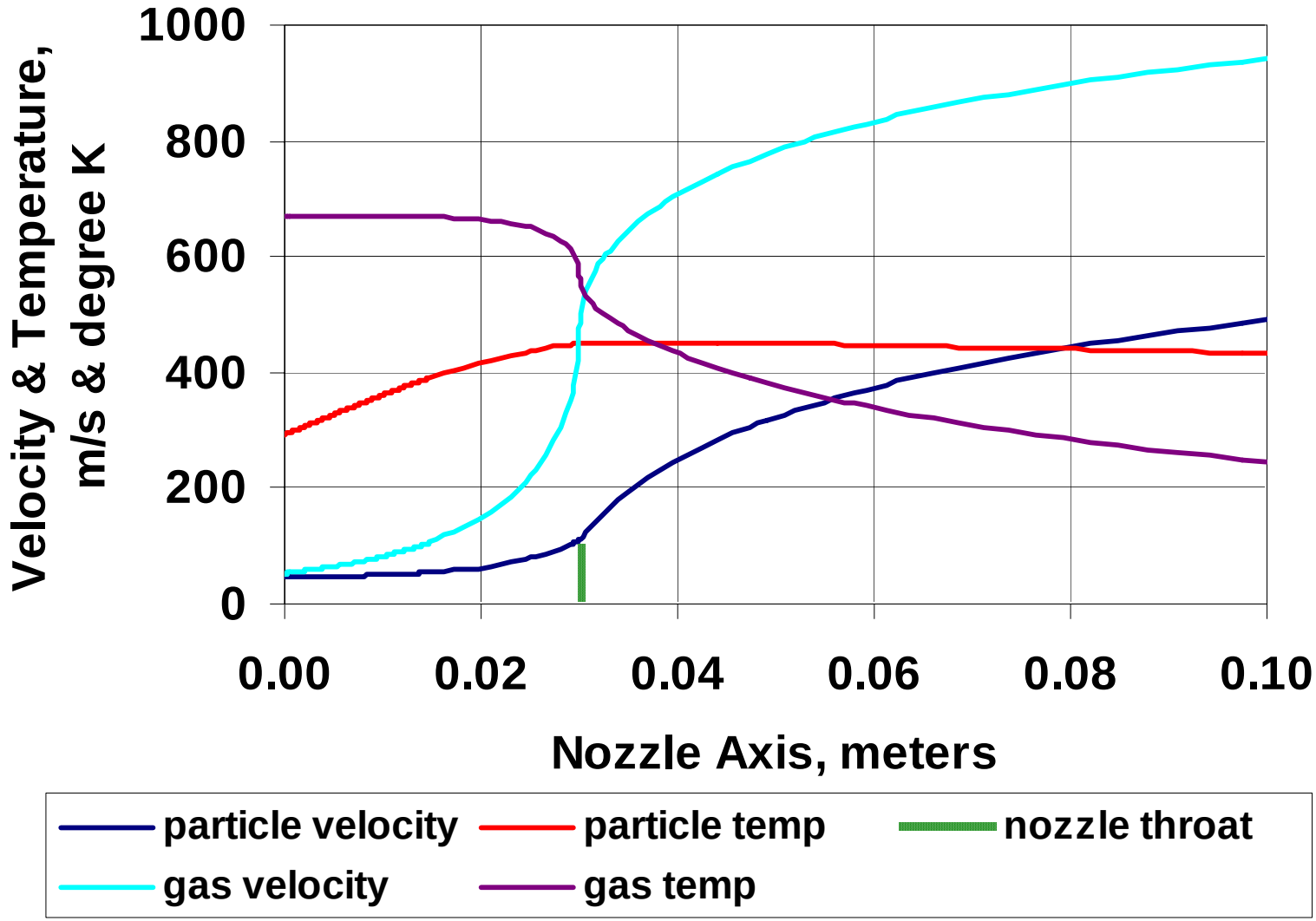
Modeling Efforts

Nozzle flow equations are used to calculate gas velocity and temperature within the nozzle.

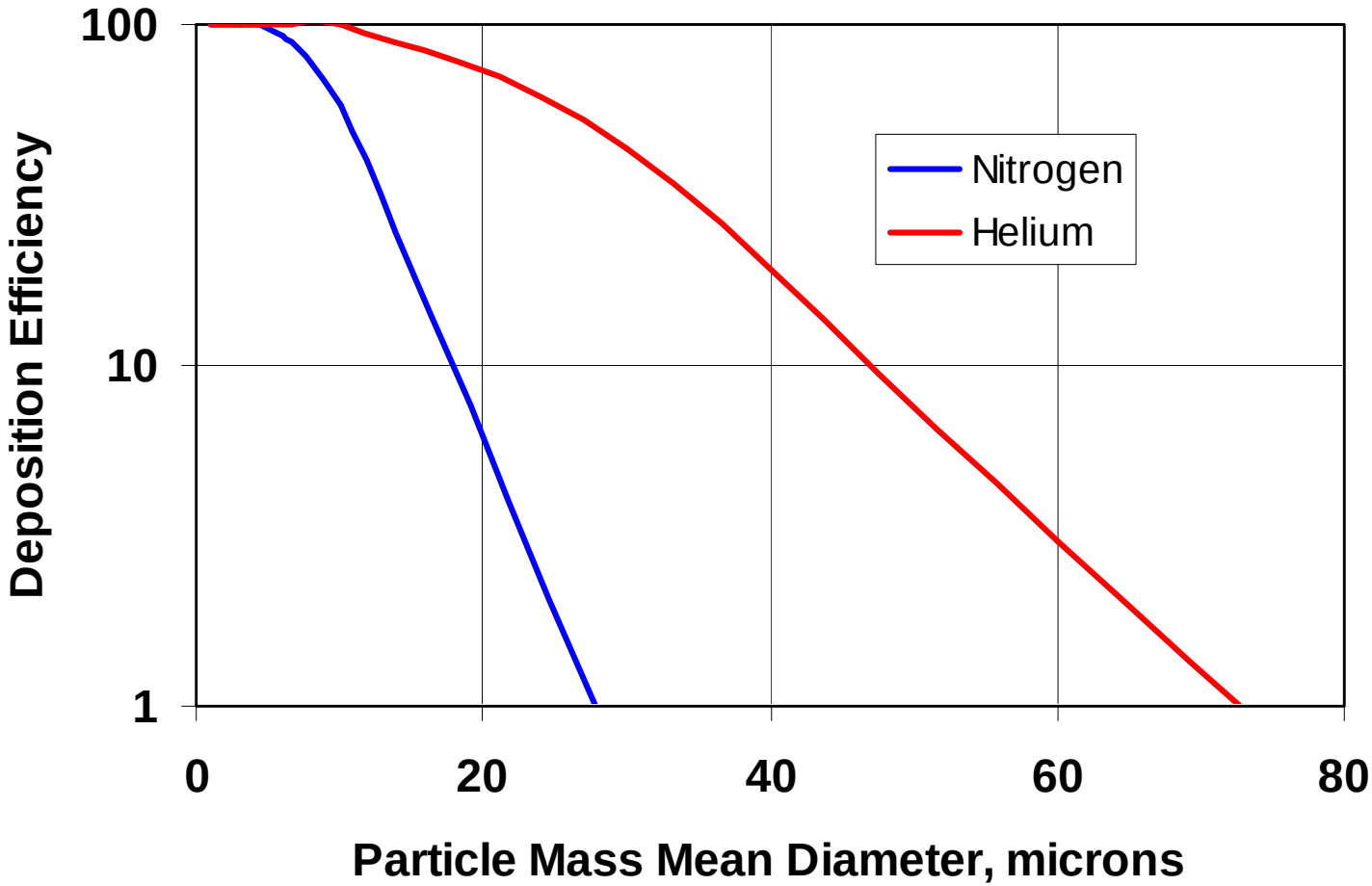
The resulting particle velocity and temperature are then calculated by gas-particle drag and heat transfer.

An empirical relationship between critical velocity and particle material characteristics is used to determine deposition efficiency.

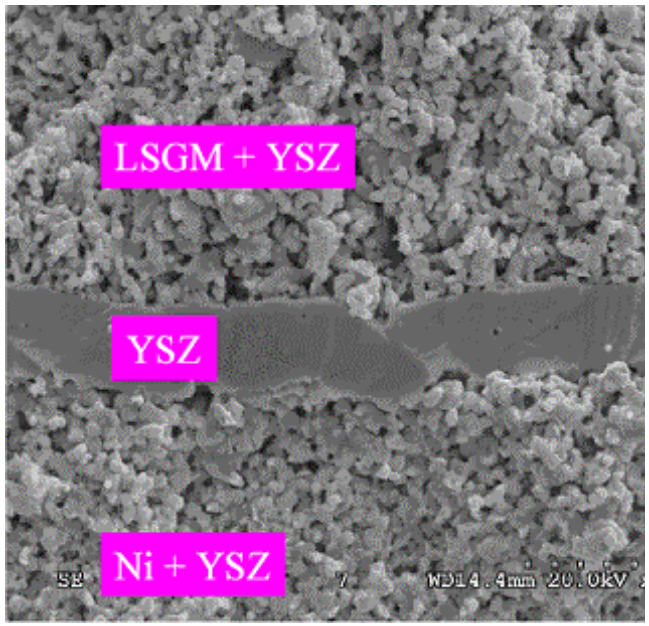
Typical Calculation

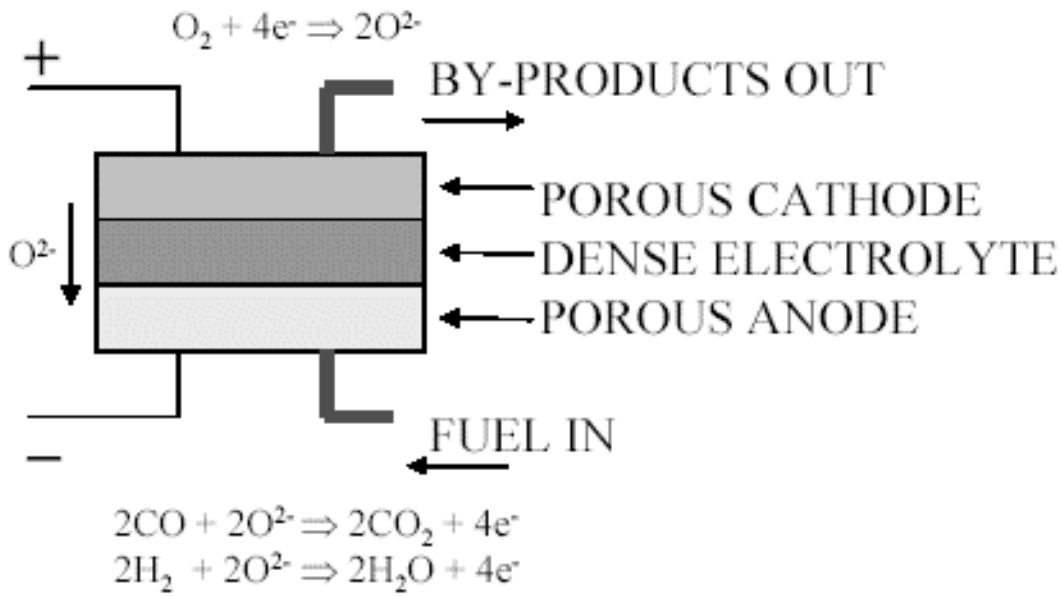


Effect of Particle Diameter on Deposition Efficiency



SPD Fuel Cell Concept





SOFC Anode Construction

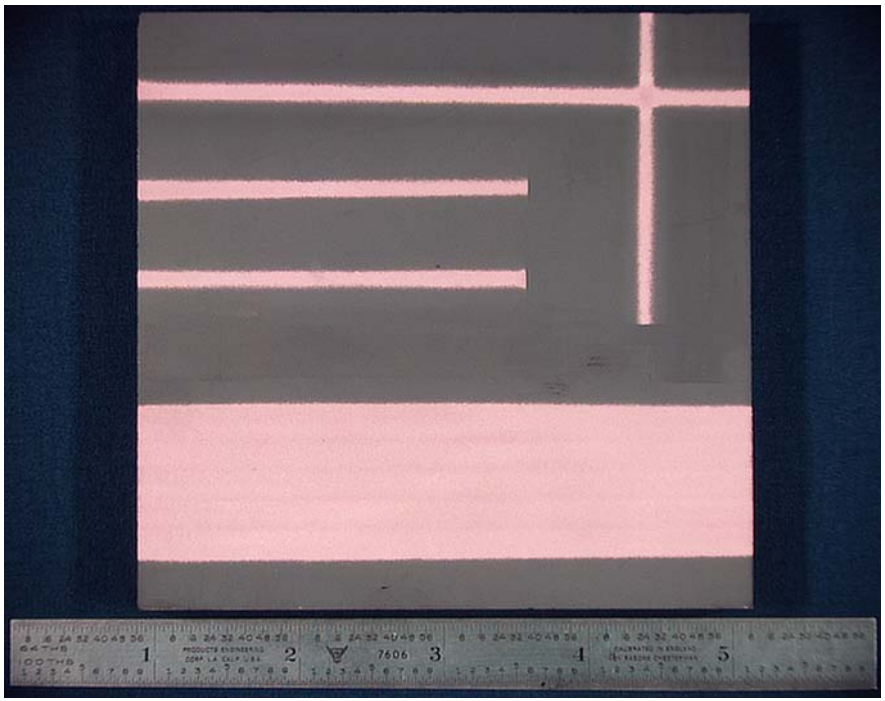
Conventional Method

- Tape cast YSZ with organic filler
- Bake out organic
- Deposit NiO
- Reduce to Ni with hydrogen

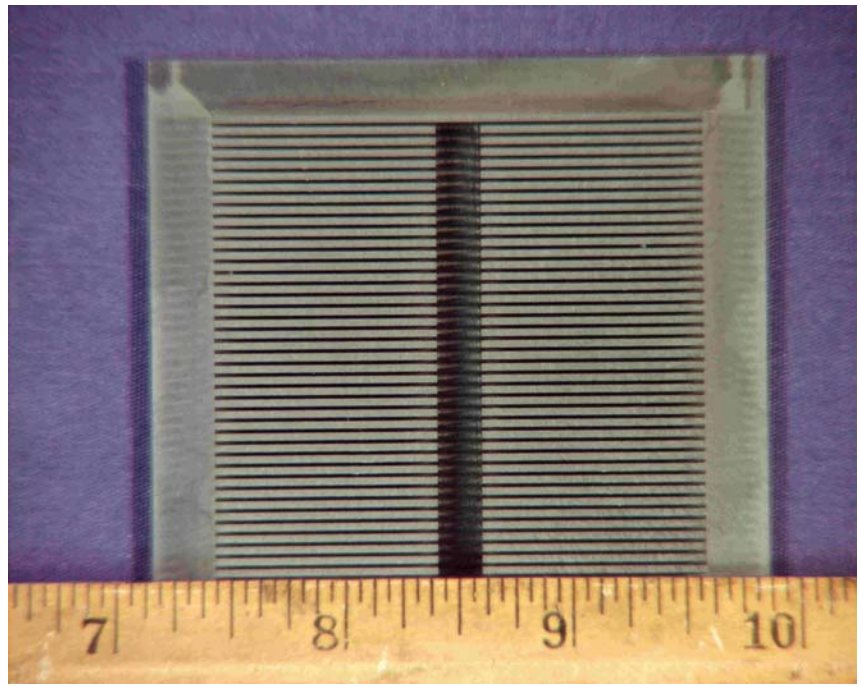
SPD Deposition

- Mix YSZ and nickel powders
- Deposit mixture with SPD

Improved Heat Exchanger



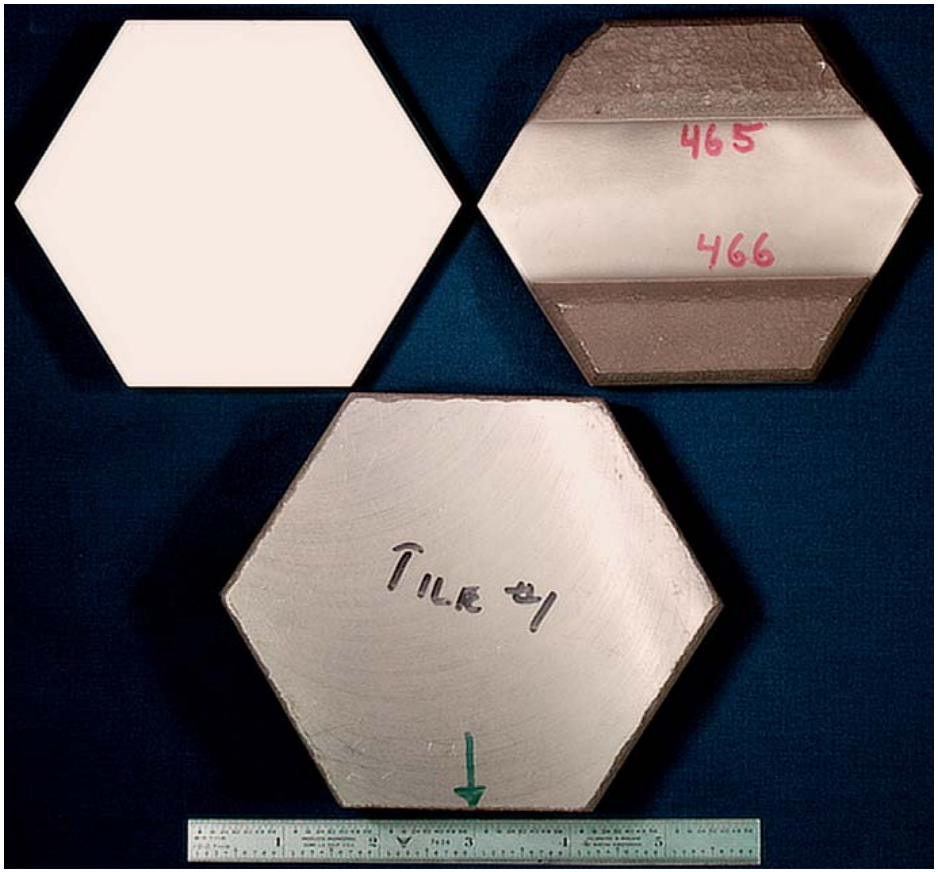
Copper on SiC

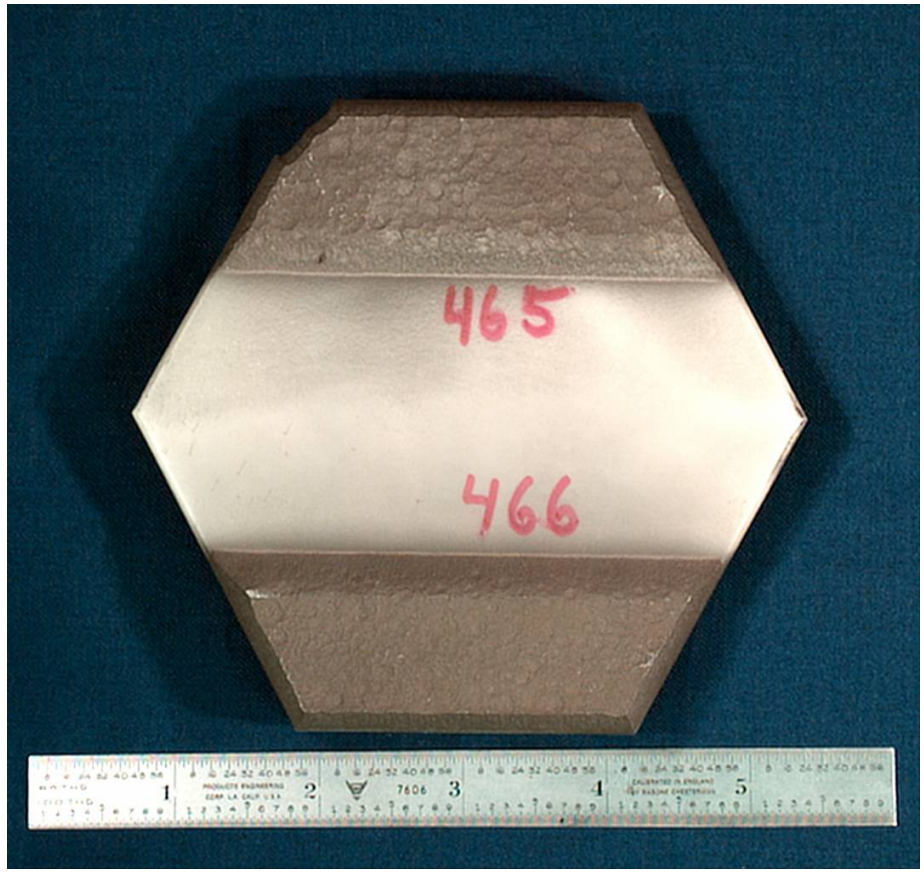


Al-SiC heat exchanger

Other ceramics include alumina & aluminum nitride

Develop SPD Parameters



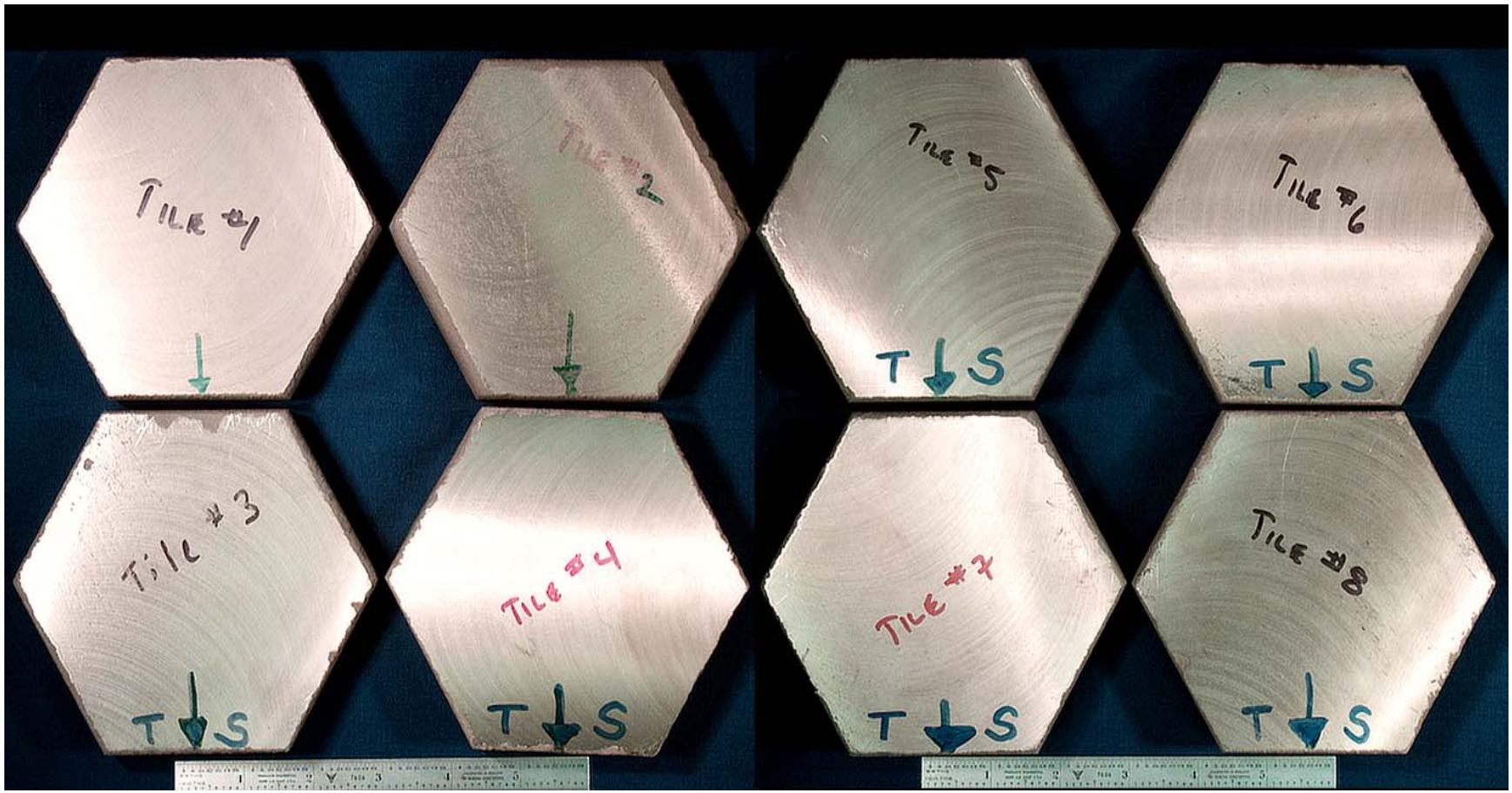


As-received 4x4x.55in Al_2O_3 ceramic tile prior to Cold Spray.

Initial test runs using sponge Ti displayed ‘orange peel’ surface (465).

Encapsulated tile (Tile #1).

8 Al_2O_3 tiles encapsulated with .25in of Ti.



CERAMIC ARMOR

TILE ENCAPSULATION

Complete coating characterization studies:

*adhesion, density, hardness, microstruture

Ballistically test encapsulated tiles:

*perform hot isostatic pressing if required

Establish process parameters to encapsulate SiC tiles:

* conduct cold spray simulation studies for Ti6Al4V

* investigate alternative coating materials

* encapsulate additional tiles with best candidate